5

LABORATORY EXPERIMENTS IN WATER TREATMENT.

By EDWARD BARTOW and J. M. LINDGREN.

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LABORATORY EXPERIMENTS IN WATER TREATMENT.

By Edward Bartow and J. M. Lindgren.

The water supplies of the University of Illinois and of the cities of Champaign and Urbana, Illinois, are obtained from wells about 160 feet deep. The water of the two supplies is of the same character and is similar to that from many wells throughout the state. The University of Illinois water may thus be considered as a type and results of experiments with it are applicable to many other waters of the state.

IONS.		HYPOTHETICAL COMBINATIONS		
PARTS PER MILLION			Parts per Million	Grains per Gallon
Potassium K	2.6	Potassium Nitrate KNO_3	1.1	.06
Sodium Na	29.0	Potassium Chloride KCl	2 9	.17
Ammonium NH_4	2.3	Sodium Chloride $NaCl$	3.5	.20
Magnesium Mg	34.9	Sodium Sulphate Na_2SO_4	3.6	.21
Calcium Ca	70.1	Sodium Carbonate Na_2CO_3	60.5	3.52
Iron Fe	1.0	Ammonium Car. $(NH_4)_2CO_3$	6.1	.36
Alumina Al	1.3	Magnesium Carbonate $MgCO_3$	121.2	7.07
Nitrate NO_3	.7	Calcium Carbonate $CaCO_3$	175.2	10 22
Chlorine Cl	3 5	Iron Carbonate $FeCO_3$	2.1	.12
Sulphate SO_4	2.3	Alumina Al_2O_3	2.5	.15
Silica SiO_2	18.9	Silica SiO_2	18.9	1.10
		Total	397.6	23.18

The water from the university wells, as shown by the analysis, contains small amounts of chlorides, nitrates and sulphates, and a considerable quantity of carbonates. The carbonates are combined with sodium, calcium, magnesium and iron.

On exposure to the air the water becomes turbid. A considerable quantity of sediment collects in the mains. This sediment varies in color from black to red according to the degree of oxidation of the iron salts. There is frequently trouble from crenothrix, and beggiatoa which is re-

Presidents office

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sponsible for an unpleasant odor has been isolated. In boilers there is a formation of sludge or a soft scale which may clog the feed pipes. Corrosion of the joints and valves is frequent. Tea kettles are incrusted, and water backs in the ranges and furnaces are clogged by the water of the same character from the city supply.

Complaints in regard to the sediment have been made to the water survey by the departments of Dairy Husbandry and Photography, and the director of the gymnasiums complains of the character of the water in the swimming pools.

Experiments were undertaken in the State Water Survey laboratory to determine the possibility of remedying these evils.

The first experiments were performed by Mr. W. F. Wheeler during the summer of 1906.

Considering that a successful treatment would be indicated when the alkalinity to phenolphthalein was one half the alkalinity to methyl orange, varying amounts of lime were added to portions of the water, the precipitate was filtered off and alkalinity determined in the filtrate. It was found that considerably more lime was needed to obtain the relation of 1 to 2 than could be accounted for by the removal of salts of calcium and magnesium. We thought this due to the fact that the lime was added in powdered form, (prepared by treating lime with one-third its weight of water), and that a considerable residue of calcium hydroxide remained in the precipitate. Later experiments show this theory to be erroneous.

Determinations of the alkalinity to phenolphthalein and methyl orange at varying intervals up to twenty-four hours after the addition of the lime indicated that the reaction was practically complete in six hours. Beyond six hours, there was a slight reaction.

The second experiment, (by the writers), was with lime water instead of the dry lime. The theoretical amount was determined by analysis and then the treatment tried on a large scale, but the results were no nearer the theoretical than before.

The third experiment was planned in order to explain the action of the excess of lime and to determine, if possible, what actually took place during the treatment. A series of tests was arranged which would show the effect of varying amounts of lime on the alkalinity and also the effected reduction on salts of calcium and magnesium.

Into each of nineteen glass stoppered bottles of about two liters capacity was measured a liter of water, taken directly from the University well.

To each portion of water was added lime water, (10 c. c. of which was equivalent to 24 parts calcium carbonate) in increasing amounts from 24 to 720 parts per millon of calcium oxide (in terms of calcium carbonate.) Since the previous experiments showed that the reaction was practically completed at the end of six hours, it was decided to use this time period for the reactions. At the end of six hours the precipitate formed in each bottle was filtered off and the alkalinity to phenolphthalein and methyl orange and the magnesium and calcium content of the filtrates were determined.

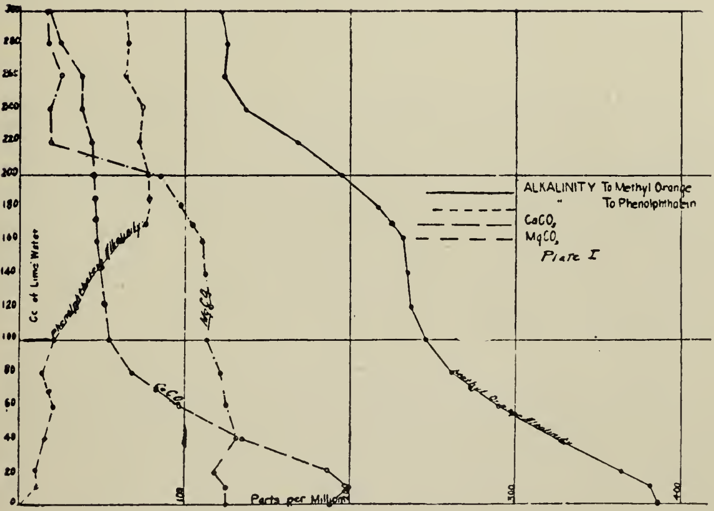
The results of the determination of the alkalinity and the content of calcium and magnesium are shown in table I and a diagramatic representation is shown on plate I. The alkalinity to methyl orange rises at first, then falls until 100 c. c., of the lime water was added, then remains constant for 60 c. c., then falls and finally rises. The calcium is shown to be removed for the most part on addition of the first 100 c. c., during which time the alkalinity to methyl orange falls. The magnesium is scarcely decreased until 200 c. c. of the lime water have been added, after which it is rapidly removed. Undoubtedly the reactions take place in order almost quantitatively, though some overlapping may be seen.

The first reaction is evidently between the lime water and the carbonic acid present. The second between the lime water and the calcium acid carbonate present, with the removal of calcium carbonate. The third reaction is the reaction between the lime water and sodium acid carbonate with the formation of sodium neutral carbonate, and the

TABLE NO. 1.

Treatment of the University of Illinois Water Supply With Lime.

No.	Lime Water	Amount of Lime Used	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium	
			Filtrate	Corrected for Volume	Filtrate	Corrected for Volume	CaO in '250 c. c.	$CaCO_3$ Cor. for Vol.	$Mg_2\ _2O_7$ from 250 c. c.	As $MgCO_3$ Cor. for Vol.
	C. C.	Parts Per Million	Parts Per Million	Parts Per Million	Parts Per Million	Parts Per Million	Mille-grams	Parts Per Million	Mille-grams	Parts Per Million
1	0	0	0	0	387.5	387.5	26.5 mg.	188.7	33.1	124.4
2	10	24	11.5	11.7	378.0	381.8	27.5	198.6	33.2	126.0
3	20	48	10.5	10.7	354.9	361.9	25.8	187.5	33.8	118.0
4	40	96	16.8	17.5	312.9	325.4	18.0	133.9	36.0	131.6
5	60	144	18.9	20.1	270.9	287.1	12.9	97.4	40.5	126.0
6	70	168	12.6	13.5	256.2	274.1	10.8	82.3	39.4	126.0
7	80	192	12.6	13.6	241.5	260.8	9.0	69.0	37.3	121.6
8	100	240	18.9	20.8	222.6	244.9	7.1	54.9	34.2	113.6
9	120	288	31.5	35.3	212.1	237.6	6.6	52.6	34.5	116.0
10	140	336	42.0	47.9	203.7	232.2	5.3	43.2	32.7	112.0
11	160	384	52.5	60.9	200.5	232.6	5.7	46.2	31.9	110.8
12	170	408	65.1	76.2	193.2	226.0	5.7	46.7	30.4	105.2
13	180	432	66.3	78.2	184.8	218.1	5.7	48.4	27.8	99.6
14	200	480	65.1	78.1	163.8	196.6	5.5	46.7	23.4	84.4
15	220	528	58.8	71.7	138.6	169.1	5.1	43.9	5.3	19.2
16	240	576	58.8	72.9	111.3	138.0	4.5	39.7	5.2	19.2
17	260	624	52.5	63.3	98.7	124.4	4.4	38.9	7.7	27.6
18	280	672	50.4	64.5	98.7	126.3	7.0		5.0	19.2
19	300	720	48.3	62.8	94.5	122.8	6.3		4.8	19.2


ALKALINITY To Methyl Orange
" To Phenolphthalein
CaCO3
MgCO3
Plate I
Cc of Lime Water
Parts per Million
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
100
200
300
400
Phenolphthalein Alkalinity
MgCO3
CaCO3
Methyl Orange Alkalinity

precipitation of calcium carbonate. During this phase the alkalinity to methyl orange remains constant, the alkalinity to phenolphthalein alkalinity rises. The fifth stage is the reaction between the lime water and magnesium carbonate with the precipitation of magnesium hydrate and calcium carbonate, during which phase the alkalinity to both methyl orange and phenolphthalein decreases.

The series of tests shows the necessity of considering the sodium acid carbonate present, since it must be changed to the neutral carbonate before the magnesium is precipitated. These experiments also suggest the advisability of considering whether it would be profitable to remove both calcium and magnesium or only the calcium.

From table I we note that 71% of the carbonate of calcium or about 50% of the combined carbonates of calcium and magnesium are removed by 134 parts per million of calcium oxide, (240 parts per million as calcium carbonate), equivalent to 7.82 grains per gallon or 1.1 pounds per thousand gallons. On a basis of 50 cents per hundred as the price of lime, this treatment will cost 55-100 cents per thousand gallons.

If on the other hand it be desired to obtain the maximum (80%) removal of these compounds, it will be necessary to add 296 parts per million or 17.26 grains per gallon or 2.46 pounds per thousand gallons. This would more than double the cost with an increase of only 30% of carbonates removed.

To further test our results a water was chosen, which had a greater amount of sodium carbonate and less of the carbonates of calcium and magnesium.

An analysis of the water gave the following results:

IONS.		HYPOTHETICAL COMBINATIONS		
PARTS PER MILLION			Parts per Million	Grains per Gallon
Potassium K	4.9	Potassium Nitrate KNO_3	.6	.03
Sodium Na	84.4	Potassium Chloride KCl	9.0	.52
Ammonium NH_4	10.8	Sodium Chloride $NaCl$	15.2	.89
Magnesium Mg	30.1	Sodium Sulphate Na_2SO_4	4.4	.26
Calcium Ca	55.9	Sodium Carbonate Na_2CO_3	177.2	10.33
Iron Fe	6.6	Ammonium Car. $(NH_4)_2CO_3$	28.7	1.67
Alumina Al	1.4	Magnesium Carbonate $MgCO_3$	104.2	6.07
Nitrate NO_3	.4	Calcium Carbonate $CaCO_3$	139.5	8.13
Chlorine Cl	13.5	Iron Carbonate $FeCO_3$	13.7	.80
Sulphate SO_4	3.0	Alumina Al_2O_3	1.4	.08
Silica SiO_2	17.7	Silica SiO_2	17.7	1.03
Bases	.6	Bases	.6	.03
		Total	512.2	29.84

This water was treated with lime water using varying amounts as in the previous experiment. The results obtained with this water, are shown in table II and in diagramatic representation on Plate II. It will be noted that the curve representing alkalinity to methyl orange is of the same general character as on Plate I. The decrease of alkalinity during the precipitation of calcium is less. While the reaction is taking place between the lime and sodium bicarbonate the alkalinity does not vary and the corresponding line is longer, corresponding quite closely to the relative amounts of the sodium bicarbonate present in the two waters.

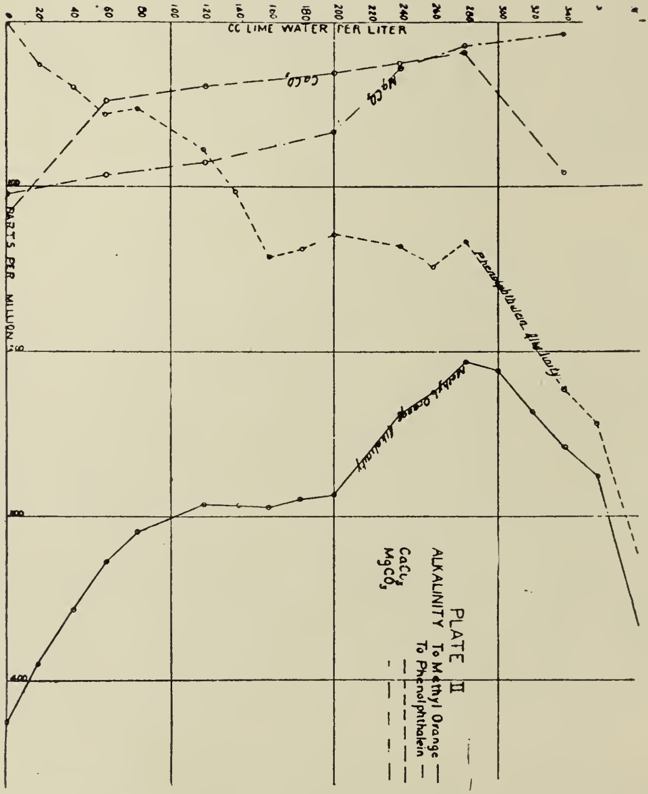


PLATE II

CC LIME WATER PER LITER
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
PARTS PER MILLION
400
CaCO3
MgCO3
Phenolphthalein Alkalinity
Methyl Orange Alkalinity
ALKALINITY To Methyl Orange
To Phenolphthalein
CaCO3
MgCO3

TABLE II.

Treatment of Water from Deep Well of Illinois Hotel Co., Bloomington, Illinois, with Lime.

No.	Lime Water Cubic Centimeters	Amount of Lime Used Milligrams per Liter	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium	
			Filtrate Parts per Million	Corrected for Volume Parts per Million	Filtrate Parts per Million	Corrected for Volume Parts per Million	CaO in 250 c. c. Milligrams	$CaCO_3$ Cor. for Volume Parts Per Million	$Mg_2P_2O_7$ From 250 c. c. Milligrams	As $MgCO_3$ Cor. for Volume Parts Per Million
1	0	0	.0	.0	423.	423.	9.	118.1		
2	5	44	25.0	26.0	378.	386.				
3	10	88	38.	39.	343.	357.				
4	15	132	52.	56.	309.	327.	5.3	49.9	23.6	93.8
5	20	176	48.4	52.	287.	310.				
6	30	264	69.	78.	261.	292.	3.4	33.9	20.1	85.2
7	35	308	90.	103.	256.	292.				
8	40	352	122.	141.	254.	295.	3.0	30.9	18.8	82.4
9	45	396	118.	139.	245.	290.				
10	50	440	108.	129.	239.	287.	3.0	31.9	14.8	67.2
11	60	528	109.	135.	192.	237.	2.2	24.2	6.2	29.1
12	65	572	118.	148.	179.	225.				
13	70	616	104.	133.	162.	207.			2.4	14.5
14	75	660	124.	161.	162.	210.				
15	80	704	147.	194.	178.	236.				
16	85	748	166.	222.	194.	259.	7.8	92.	1.8	9.0
17	90	792	178.	243.	202.	274.				
18	100	880	242.	338.	267.	373.				

In this case an amount of lime equal to 74 parts per million or 4.31 grains per gallon or 6 lb for 1000 gallons, removed 58% of the calcium carbonate or 35% of the combined carbonates of magnesium and calcium. The cost of this removal would be 3/10 of a cent per 1000 gallons.

In order to reach the highest efficiency, a removal of 82% of the combined carbonates, it would be necessary to add 345 parts per million of pure lime equivalent to 20.1 grains per gallon or 2.86 pounds per thousand gallons.

To try to determine the correctness of our hypothesis, that the sodium bicarbonate interferes with the precipitation of magnesium by means of lime, we substituted sodium hydroxide for calcium oxide in a similar series of tests. The solution of sodium hydroxide was made of ten times the strength of the lime water, and 1/10 the amount was used in each case. Adding such a small amount of the solution, no correction was made for dilution. The results obtained are shown in Table III and are diagramatically represented on Plate III. An inspection of the results shows that the calcium acid carbonate is removed with one-half of an equivalent amount of sodium hydroxide; that the alkalinity to methyl orange decreases slightly until the calcium is removed, after which it increases steadily; and that the magnesium is removed at about the same time, as with calcium oxide, but more slowly. The results confirm the hypothesis that the sodium acid carbonate delays the precipitation of magnesium. A comparison of Plates I and III would indicate that there would be no advantage in using sodium hydroxide rather than lime to soften a water like the University of Illinois supply. The calcium acid carbonate would be removed with the formation of less sludge, but the increase in soluble residue would more than offset this advantage.

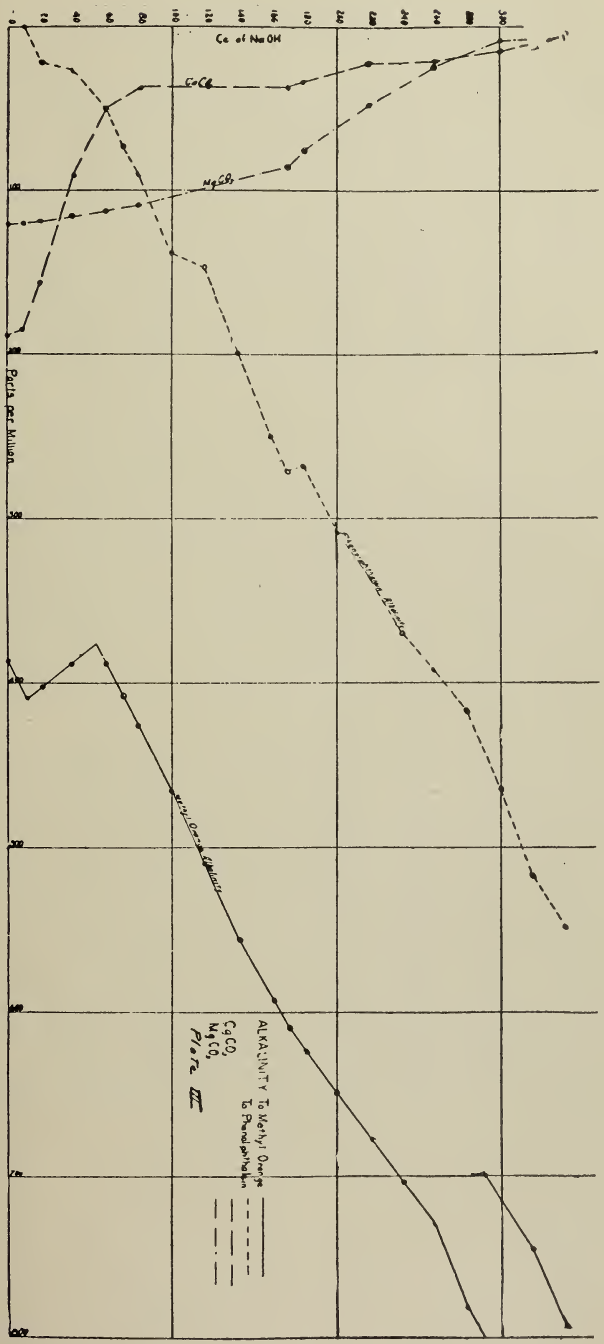

Cc of NaOH
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
100
200
300
400
500
600
700
800
Parts per Million
CaCl₂
MgCl₂
Phenolphthalein Alkalinity
Methyl Orange Alkalinity
ALKALINITY To Methyl Orange
To Phenolphthalein
CaCO₃
MgCO₃
Plate III

TABLE III.

Treatment of the University of Illinois Water Supply with Sodium Hydroxide.

					Calcium		Magnesium	
No	Sodium Hydroxide Solution c. c.	Amount of Sodium Hydroxide Used Milligrams	Alkalinity to Phenolphthalein Parts per Million	Alkalinity to Methyl Orange Parts per Million	CaO in 250 c. c. Milligrams	$CaCO_2$ Parts per Million	$Mg_2P_2O_7$ From 250 c. c. Milligrams	$MgCO_3$ Parts per Million
1	0	0	0	386.	26.5	189.1	39.7	120.5
2	1	17	0.	405.	26.0	185.5	39.8	120.5
3	2	34	22.	403.	22.1	157.8	38.3	118.8
4	4	68	26.	388.	12.8	91.3	38.1	118.4
5	6	102	50.	388.	7.2	50.4	37.4	113.2
6	7	119	72.	406.				
7	8	136	90.	426.	5.4	38.4	36.1	109.4
8	10	170	139.	468.				
9	12	204	147.	511.				
10	14	238	198.	555.				
11	16	272	248.	589.				
12	17	299	270.	609.	5.4	38.4	28.5	86.2
13	18	316	266.	622.	4.5	32.0	25.3	76.5
14	20	340	307.	650.				
15	22	374	334.	673.	3.0	21.2	15.8	47.8
16	24	408	369.	702.				
17	26	442	393.	728.	2.9	20.5	6.8	20.4
18	28	476	417.	780.				
19	30	510	463.	813.	2.1	15.0	3.2	9.7
20	32	544	518.	845.				
21	34	578	549.	893.	.8	5.5	2.2	6.6

Since the waters of the State of Illinois may be hypothetically divided into two classes, those containing sodium carbonate and those containing magnesium sulphate, we next experimented with a magnesium sulphate water.

For this purpose we chose a water from a shallow well at the plant of the Dean & Bode Manufacturing Co., Champaign, Illinois. This water forms a hard scale when used in boilers, and is another type of water common in this State. An analysis of the water follows:

IONS		HYPOTHETICAL COMBINATIONS		
PARTS PER MILLION			Parts per Million	Grains per Gallon
Sodium Na	33.4	Sodium Nitrate $NaNO_3$	1.6	.09
Magnesium Mg	50.0	Sodium Chloride NaCl	39.6	2.31
Calcium Ca	106.9	Sodium Sulphate Na_2SO_4	53.7	3.13
Oxide of Iron and Alumina	2.2	Magnesium Sulphate $MgSO_4$	145.7	8.49
Nitrate NO_3	1.2	Magnesium Carbonate $MgCo_3$	36.4	2.12
Chloride Cl	24.0	Calcium Carbonate $CaCO_3$	266.8	15.56
Sulphate SO_4	152.5	Oxide of Iron Fe_2O_3 + and Alumina Al_2O_3	2.2	.13
“ Sio_2	11.0	Silica SiO_2	11.0	.64
Bases	3.0	Bases	3.0	.17
		Total Mineral Matter	560.0	32.64

The first experiment with the magnesium sulphate water was carried out in the same way as the first experiment with the sodium carbonate water. The results are shown in Table IV, with a diagramatic representation on Plate IV. An inspection of Plate IV shows that the first reaction is between the lime water and the free carbon dioxide. The second is the removal of calcium carbonate. The third is evidently a neutralization of magnesium acid carbonate and the change from magnesium sulphate to calcium sulphate. The fourth is a decrease in the magnesium content.

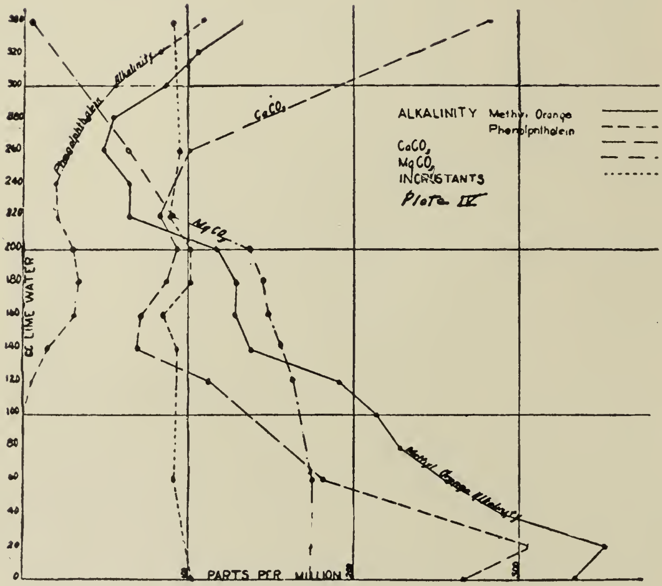

340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
CC LIME WATER
PARTS PER MILLION
50
100
150
Phenolphthalein Alkalinity
CaCO3
MgCO3
Methyl Orange Alkalinity
ALKALINITY Methyl Orange
Phenolphthalein
CaCO3
MgCO3
INCRUSTANTS
Plate IV

TABLE IV.

Treatment of Water From Shallow Well, Champaign, Illinois, With Lime.

No.	Lime Water Used c. c.	Amount of Lime Used	ALKALINITY TO PHENOLPHTHALEIN		ALKALINITY TO METHYL ORANGE		CALCIUM		MAGNESIUM		Incrustants
			Filtrate	Corrected for Volume	Filtrate	Corrected for Volume	CaO in 250 c. c.	$CaCO_3$ Cor. for Vol.	$Mg_2P_2O_7$ From 250 c. c.	As $MgCO_3$ Cor. for Vol.	
		Milligrams	Parts Per Million	Parts Per Million	Parts Per Million	Parts Per Million	Milligrams	Parts Per Million	Milligrams	Parts Per Million	Parts Per Million
1	0	0	0	0	332	332	37.4	266.4	57.1	173.1	103.9
2	20	41		0	345	351	42.3	307.6	56.5	174.5	
3	40	82	0	0	279	290					
4	60	124	0	0	236	255	24.0	181.6	53.6	174.5	91.7
5	80	165	0	0	209	228					
6	100	206	0	0	191	214					
7	120	247	6.4	7.4	169	191	14.4	114.8	48.8	164.8	93.0
8	140	287	11.9	13.6	118	137	8.5	68.8	45.6	157.9	94.6
9	160	330	25.7	31.0	110	128	8.6	70.8	42.2	148.2	85.4
10	180	371	29.4	35.	108	128	10.4	86.8	41.3	146.8	102.0
11	200	412	25.7	31.	94	118	11.1	93.8	38.1	137.1	104.0
12	220	453	18.3	22.	53	64	9.5	82.8	24.1	90.0	89.8
13	240	494	16.5	20	51	64					
14	260	536	23.0	29	39	48	11.3	99.6	15.8	63.6	95.0
15	280	577	31.2	40	42	54					
16	300	618	41.	54	66	86					
17	320	659	62.4	82	83	104					
18	340	700	82.6	110	101	133	29.6	282.5	1.3	5.5	91.2

An additional determination of incrustants was made on the water. The incrustants remained constant throughout the series, the amounts of calcium never decreased below 69 parts per million and the calcium increased as the magnesium decreased probably replacing the magnesium in the sulphate. In a water of this class no advantage is obtained by adding more than sufficient lime to remove the carbonates.

A discussion of the comparative cost of removing the calcium carbonate and total alkalinity would therefore be superfluous. The maximum amount of lime, if used alone, would be 161 parts per million, 9.39 grains per gallon or 1.3 pounds per thousand gallons.

A similar series of tests was made using a solution of sodium carbonate of the same strength as the lime water. The results of this experiment are shown in Table V, and are represented diagramatically on Plate V. In the first stage of the reaction the free carbon dioxide reacts with the sodium carbonate; in the second stage the incrustants decrease at the same time the calcium carbonate decreases. During the remainder of the series, there were no important changes, the magnesium carbonate remaining constant throughout the entire series. This experiment would show that it is profitable to treat this type of water with sodium carbonate alone, but that the amount should not exceed a quantity sufficient to remove incrustants and calcium carbonate. An excess should be avoided as the alkalinity would be increased and at the same time there would be an increase in the soluble residue which would make the treated water liable to foam.

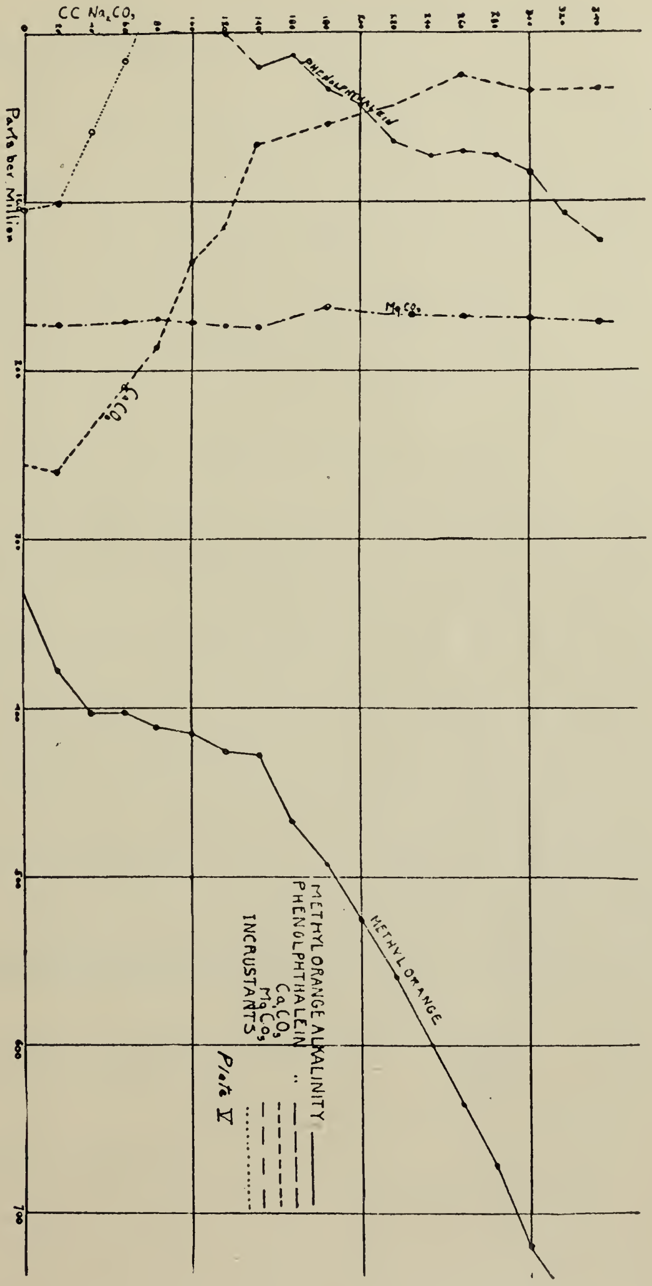

CC Na_2CO_3
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Parts per Million
100
200
300
400
500
600
700
PHENOLPHTHALEIN
$MgCO_3$
$CaCO_3$
METHYL ORANGE
METHYLORANGE ALKALINITY
PHENOLPHTHALEIN ..
$CaCO_3$
$MgCO_3$
INCRUSTANTS

Plate V

TABLE V.

Treatment of Water From Shallow Well at Champaign, Illinois, With Sodium Carbonate.

No.	Sodium Carbonate Solution c. c.	Amount of Sodium Carbonate Used	Alkalinity to Phenolphthalein		Alkalinity to Methyl Orange		Calcium		Magnesium		Incrustants
			Filtrate	Corrected for Volume	Filtrate	Corrected for Volume	CaO in 250 c. c.	$CaCO_3$ Corrected for Volume	$Mg_2P_2O_7$ from 250 c. c.	As $MgCO_3$ Cor. for Volume	
		Milligrams	Parts Per Million	Parts Per Million	Parts Per Million	Parts Per Million	Milligrams	Parts Per Million	Milligrams	Parts Per Million	Parts per Million
1	0	0	0	0	334	334	36.1	257.6	57.3	173.2	103.9
2	20	22	0	0	369	376	39.4	260.4	56.6	174.3	101.0
3	40	44	0	0	391	404					59.
4	60	66	0	0	380	402	28.1	212.4	53.3	170.4	16.
5	80	88	0	0	380	411	25.7	166.8	51.8	169.0	
6	100	110	0	0	376	415	16.1	135.6	51.0	170.4	-67.
7	120	132	0	0	380	426	14.4	114.8	51.0	173.2	-91.
8	140	154	18	20	374	428	7.8	64.0	50.2	173.2	
9	160	176	11	13	404	468					-206.
10	180	198	29	33	417	492	6.7	52.8	45.5	162.1	-221.
11	200	220	35	42	437	525					-280.
12	220	242	53	64	457	558	4.9	42.8	45.5	167.6	-279.
13	240	264	59	72	481	597					-358.
14	260	286	55	70	503	633	3.1	28.8			-426.
15	280	308	57	73	525	672					-411.
16	300	330	61	83	556	722	3.9	34.0	43.1	169.	-475.
17	320	352	81	106	569	751					-620.
18	340	374	92	121	590	789	3.4	31.6	42.3	170.4	-561.

The maximum amount of sodium carbonate is 154 parts per million, 9 grains per gallon, 1.3 pounds per thousand gallons.

From the results of the two preceding experiments it was decided to combine the treatments using both sodium carbonate and lime. Therefore, a series of tests was carried out using in each test an amount of sodium carbonate which would a little more than neutralize the incrustants and varying the amounts of lime, as in the preceding experiments. The results of this experiment are shown in Table VI and are represented diagramatically on Plate VI. In this case the carbonate of calcium is reduced to a minimum more quickly than when the water was treated with lime alone. The calcium content, does not increase during the removal of the magnesium. The magnesium is precipitated at about the same point as when lime alone is used, though it comes out more rapidly than in the former case. The incrustants are shown to be negative, indicating that a slight excess of sodium carbonate was used. For this water the 106 parts per million of sodium carbonate or .88 pounds per 1000 gallons with 101 parts per million of lime or .84 pounds per 1000 gallons removed 70% of the calcium acid carbonate and 46% of the combined carbonates of calcium and magnesium. In order to obtain the maximum removal of alkaline earth carbonates (82%), 282 parts per million of pure calcium oxide would be required, equivalent to 16.44 grains per gallon or 2.3 pounds per thousand gallons for lime and 106 grains per gallon or .88 pounds per 1000 gallons of soda ash, making it cost for the removal of the calcium carbonate 1.2 cents per thousand gallons, or for combined carbonates, 2 cents per thousand gallons.

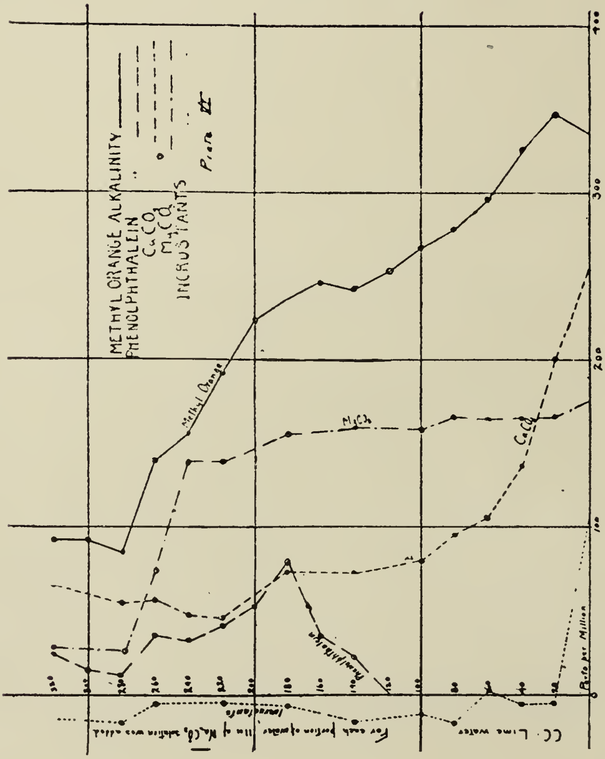

METHYL ORANGE ALKALINITY
PHENOLPHTHALEIN
$CaCO_3$
$MgCO_3$
INCRUSTANTS
Plate II
Methyl Orange
$MgCO_3$
$CaCO_3$
Phenolphthalein
Incrustants
Parts per Million
100
200
300
400
For each portion of water 1 cc of Na_2CO_3 solution was added
CC. Lime water

TABLE VI.

Treatment of Water From Shallow Well, Champaign, Illinois, With a Constant Amount of Sodium Carbonate, and Varying Amounts of Lime.

No.	Lime Water Used c. c.	Amount of Lime Used	ALKALINITY TO PHENOLPHTHALEIN		ALKALINITY TO METHYL ORANGE		CALCIUM		MAGNESIUM		Incrustants
			Filtrate	Corrected for Volume	Filtrate	Corrected for Volume	CaO in 250 c. c.	$CaCO_3$ Corrected for Volume	$Mg_2P_2O_7$ From 250 c. c.	As $MgCO_3$ Corrected for Volume	
		Milligrams	Parts Per Million	Parts Per Million	Parts Per Million	Parts Per Million	Milligrams	Parts Per Million	Milligrams	Parts Per Million	Parts Per Million
1	0	0	0	0	334	334	37.4	266.4	57.1	173.1	103.9
2	20	36	0	0	340	347	18.0	200.0	43.2	165.0	- 5.7
3	40	72	0	0	312	324	14.4	133.5	32.7	167.5	- 5.8
4	60	108	0	0	279	296	11.2	106.0	41.3	164.0	0.
5	80	144	0	0	257	278	9.8	95.0	41.1	168.	-19.
6	100	180	0	0	242	266	8.1	79.5	38.0	157.5	-13.2
7	120	216	0	0	224	251					
8	140	252	20	23	211	241	7.1	72.5	37.0	159.5	18.2
9	160	288	29	34	211	245					
10	180	324	62	79	200	236	6.9	72.5	34.3	154.0	9.4
11	200	360	44	53	185	222					
12	220	396	33	40	158	192	5.2	46.0	29.8	137.0	- 6.8
13	240	432	26	32	126	156	5.3	47.0	29.8	138.5	- 6.9
14	260	468	28	35	110	139	6.4	57.0	15.9	75.0	- 7.0
15	280	504	9	11.5	66	84	4.9	53.5	5.2	24.0	-18.0
16	300	540	11	14	70	91					
17	320	576	18	24	70	92	5.4	64.5	6.0	29.5	-15.8

NOTE—To each portion of water 11 c. c. of sodium carbonate solution containing 116.6 milligrams Na_2CO_3 was added.

SUMMARY.

Our work shows First: In a water containing sodium acid carbonate, allowance must be made for this substance when the water is treated with lime.

Second: Owing to the action of sodium bicarbonate on lime, it might pay to consider partial treatment to remove calcium carbonate alone, rather than complete treat--ment to remove magnesium carbonate also.

Third: Treatment of magnesium sulphate waters with lime alone is unsatisfactory since the sulphate of calcium remains in the solution.

Fourth: Treatment of a magnesium sulphate water with sodium carbonate alone is satisfactory if only carbonate of calcium is removed and the incrustants neutralized.

Fifth: That treatment of a magnesium sulphate water with sodium carbonate and calcium hydrate shows similar reactions to the treatment of the sodium carbonate water and that a consideration of the relative cost of partial and complete treatment is advisable.

Sixth: When it is not practicable to treat all of a supply, information as to the exact character of the water and the best method of treatment should be furnished to consumers.

DISCUSSION.

Mr. Monfort: I have listened with a great deal of interest to the abstract of the paper. The data presented is in line with a good deal of my own observation. At present my observation is not complete, and I trust at some later time to be able to compare notes with the authors of the paper. I desire now to express what I think is the feeling of the Association, our appreciation of the honor paid us in presenting the paper here.

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